Diversity of Neural Systems in Invertebrates

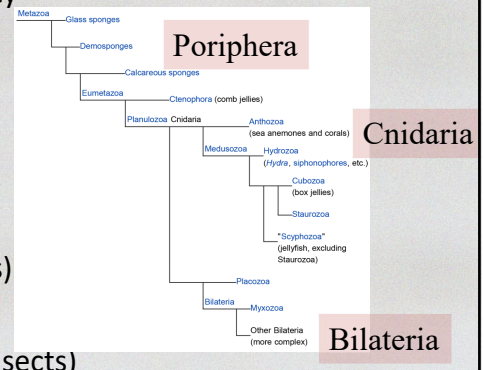
1

Overview

Overview of increasing complexity

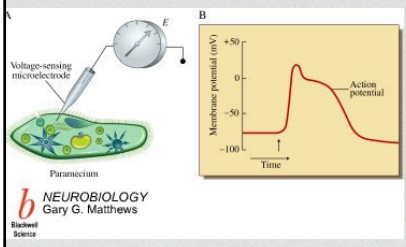
NS in the main groups:

- Poriphera (sponges)
- Cnidaria (jellyfish)
- Bilateria
- Echinoderms (starfish)
- Platyhelminthes (flatworms)
- Annelida (ringworms)
- Arthropods (crustaceans, insects)
- Molluscs (snails, squid)



2

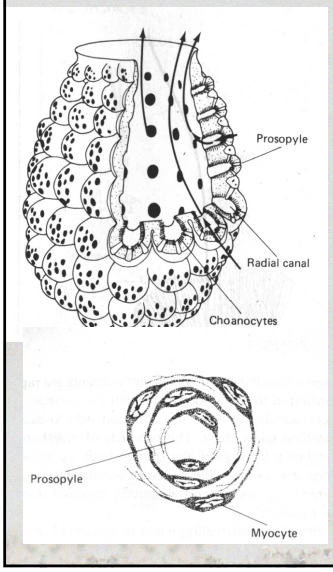
Evolution neural precursors



- Paramecium can produce action potentials - similar to nerve cells
- Action potential due to influx of calcium (Ca) rather than sodium (Na)
- Action potential regulates the direction of ciliary beating - avoidance of noxious stimuli
- Basic molecular machinery for electric signalling predates first neuron - neural signalling evolved from pre-existing mechanisms in protozoan

3

Sponges: neural precursors



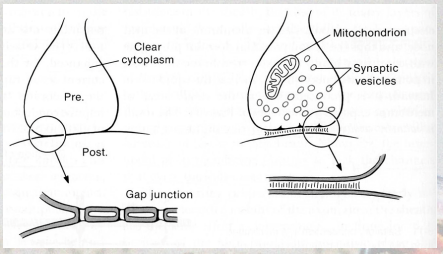
- No known neurons but can contract and alter body form
- Myocytes (contractile cells) - communicate with each other via gap junctions. Transmission speed slow: 0.26cm/sec
- Sponge behaviour: filter water…

4

Communication via synapses

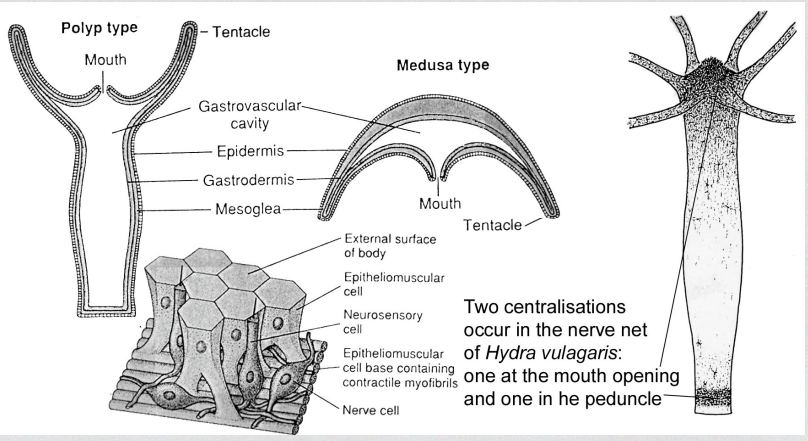
Synapses allow transfer of information from one neuron to the next

- 2 types: electrical or chemical
- Electrical synapse (gap junctions): trans-membrane channels that couple 2 cells electrically
- Chemical synapse: use chemical substances (neurotransmitters) to communicate across the gap (synaptic cleft) → slower, but much more flexible (2 ms transmission in vertebrate synapses)



5

Cnidarians: nerve nets



Already have sensory, intermediate, and motor neurons!

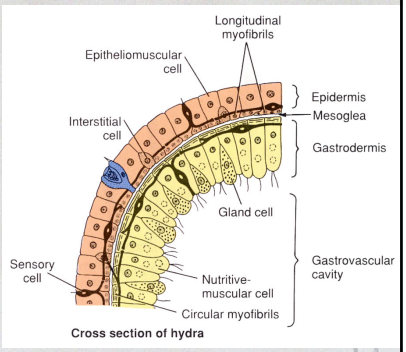
6

Cnidarians: first neuromuscular system

Nerve cells can connect to other nerve cells or to sensory or effector cells (i.e. muscle cells).

Sensory cell - neuron - epitheliomuscular network is the first neuromuscular system

Allows array of behaviours incl. swimming and feeding



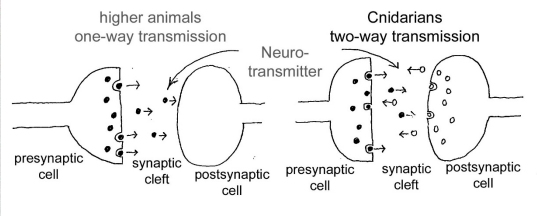
7

Cnidarians: 2-way synapses

An impulse starting in one part of the nerve is conducted in all directions - signal transmission in synapse is 2-way (unlike in higher animals)

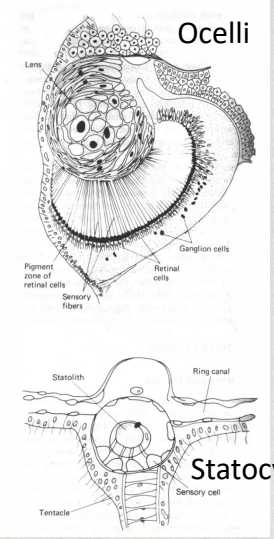
Cnidaria have both chemical synapse and gap junctions

Transmission speed 10-100cm/s



8

Sensory organs found in medusae

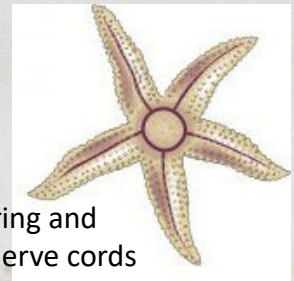


- Often well developed sensory organs - the first multicellular sensory organs in the animal kingdom!
- Ocelli - light sensitive organs, sometimes highly sophisticated with lenses, eye movements etc.
- Statocyst - sense gravity and have pacemaker function
- Ocelli & statocyst often combined in larger organ - rhopalia

9

Echinodermata (Bilateria)

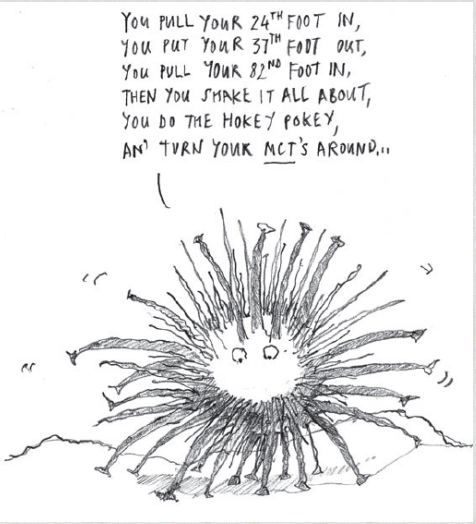
- Senses: photosensitive, chemosensitive, touch-sensitive, proprioception: but receptors unknown
- Nerve net has collapsed
- Neurons have to 'fend for themselves' (no glia cells or even blood vessels)
- Chemical synapses but no gap junctions found so far
- Planktonic larvae bilateral



Nerve ring and
radial nerve cords

10

How do echinoderms move?

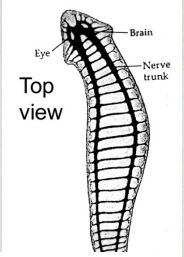

You pull your 24TH foot in,
You put your 37TH foot out,
You pull your 82ND foot in,
Then you shake it all about,
You do the Hokey Pokey,
An' turn your MCT's around...

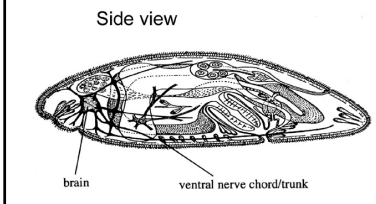
Cartoon by Pete Jeffs

- Mutable collagenous tissues (MCTs) in tube feet: can change rapidly from stiff to pliable
- Nerve terminals from the hyponeural system connect to secretory cells that control state of the MCTs
- Process of stiffening and softening most likely calcium dependent
- Normally locked (no effort)

11

Flatworms (Platyhelminths)



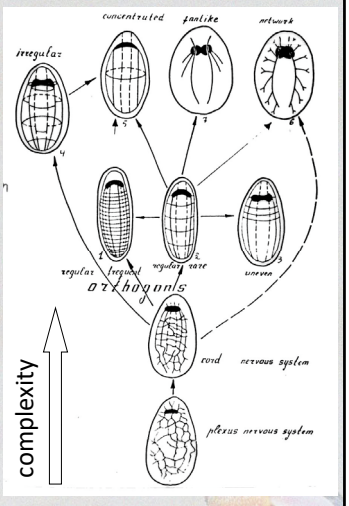


- Truly bilateral nervous system and a 'brain'
- Retain a nerve net but also have pairs of longitudinal nerve cords
- Typical ventral position of invertebrate NS
- Sensory organs: ocelli, tactile cells, chemoreceptive cells, statocysts (gravity) and rheoreceptors (sensing direction of water)
- One-way neurons - allow signal transmission only in one direction

12

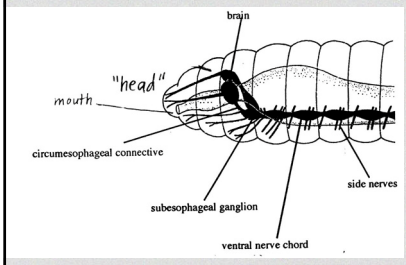
The flatworm brain & cephalisation

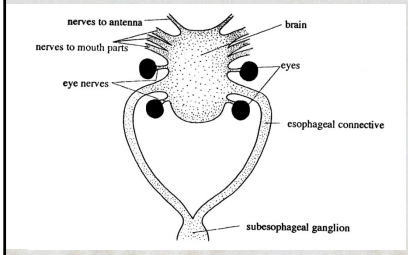
- More primitive flatworms have a net-like nervous system
- Advanced flatworms have a single pair of nerve cords and high degree of cephalisation
- Brain controls and inhibit reflexes in peripheral NS (contextual information processing!)



13

Annelid Worms and their CNS



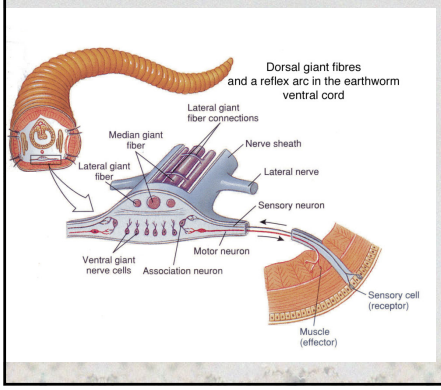


CNS contains:

- A fused pair of cerebral ganglia (the brain) above the pharynx
- A pair of circumoesophageal connectives connects brain with first pair of ganglia in the nerve
- A paired ventral nerve cord
- A fused ganglion in each segment from which side nerves branch: both sensory and motor fibres

14

Annelid worms : segmental nervous system



Segmental ganglia paved the way for functional specialisation

- local control of segmental muscles (circular and longitudinal), permitting efficient locomotion
- local reflexes involving the first true afferent and efferent pathways

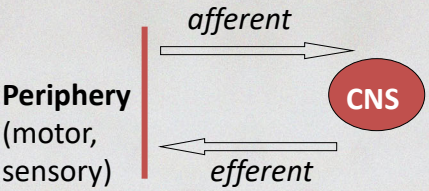
Giant fibres - fast reflexes

Sensory organs: tactile, statocyst, chemo, visual (including sophisticated eyes in some species)

15

Afferent & efferent pathways

- Afferent and efferent refers to direction of information flow between periphery and CNS
- Typical circuit: sensory organ- afferent - CNS interneuron - efferent - motor neuron
- Also possible to have efferent fibres projecting back to sensory organ - allows fine-tuning of the senses
  → predictions



16

Invertebrate CNS: Brain

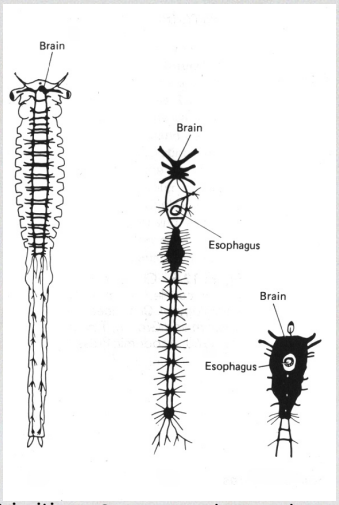
Brain defined as that mass of the nervous system that lies in head

Often invertebrate brain undistinguished, like large ganglion, in other cases highly complex

Blood-brain barrier in cephalopods, insects, higher arachnids and decapod crustaceans

17

Crustaceans

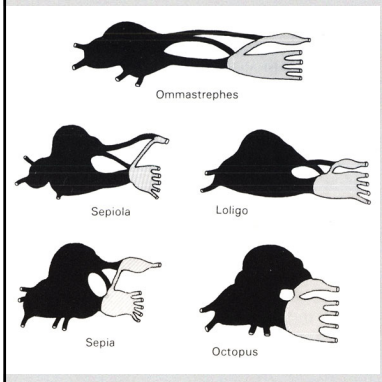


Primitive crustacean | Stomatopoda | Brachyura (crab)

Display various stages NS evolution

18

Cephalopod CNS: similarities to vertebrate brain



Generally larger than any other part of invertebrate CNS

Morphologically and functionally specialized

Similarities:

process sensory information

make decision

organize motor output

Some invertebrate brains highly sophisticated, with specialized regions for functions such as memory

19

High degree of specialisation of nervous systems in higher invertebrates

- Somatic nervous system
  - Motoneurons that innervate muscle
- Peripheral nervous system
  - Nerves and receptor cells
- Visceral/peripheral nervous system
  - Ganglia with neurons that control visceral organs (heart, stomach, gut, reproductive organs)
- Neurosecretory structures
  - Release hormones

20

Mollusc nervous systems

From simple to the most complex and largest NS in the invertebrate world

Number of neurons in CNS:

C. elegans	302
Leech	10,000
Aplysia	20,000
Lobster	100,000
Fruit fly	100,000
Honey Bee	960,000
Cockroach	1,000,000
Mouse	71,000,000
Octopus	500,000,000
Cat	1,000,000,000
Human	85,000,000,000

21

Evolution Cephalopods - pinnacle of the invertebrates

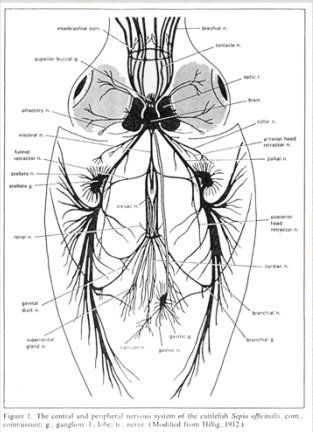


Figure 1. The central and peripheral nervous system of the cuttlefish *Sepia officinalis*. com., commissure; g., ganglion; l., lobe; n., nerve. (Modified from Hillig, 1912.)

- Peripheral NS: mainly concerned with motorcontrol
- CNS: brain divided into lobes (up to 38 in octopus)

22

Cephalopod: chromatophores

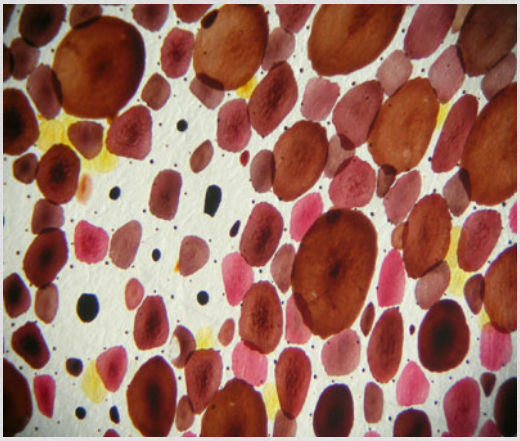
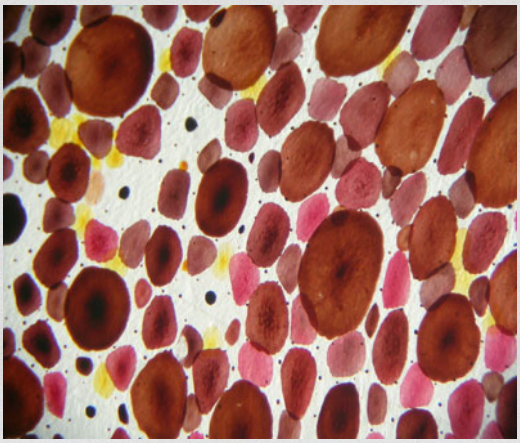


Photo: Dr L Mäthger

23

Cephalopod: chromatophores



- Colour change under nervous control → millisecond speed
- Colourblind!

Photo: Dr L Mäthger

24

Nervous system complexity I

No apparent neurons or nervous system, but neural precursors
(Action potentials in single cell organisms)

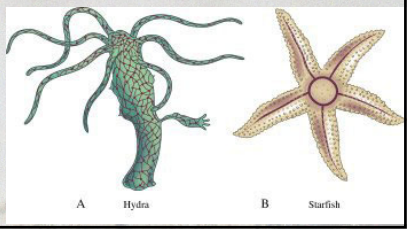
(Poriphera: sponges)

Simple, diffuse nerve nets, simple sense organs

(Cnideria: anemones, corals, jellyfish & medusa)

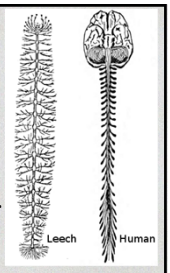
Nerve ring and extensive network of peripheral nerves

(Echinodermata: starfish etc)



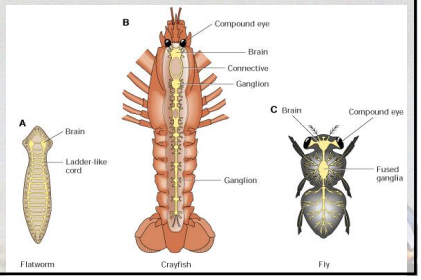
25

Nervous system complexity II



Nerve net rejected in favour of nerve cords and a true anterior brain.
Giant fibres and segmental ganglia. Simple sense organs.
Afferent and efferent neurons. (eg. Annelid worms, e.g. leeches)

Large anterior brain with regions devoted to different tasks, especially for advanced sense organs. Specialised segmental ganglia
Social behaviour & learning abilities
(eg. insects, arachnids, crustaceans)



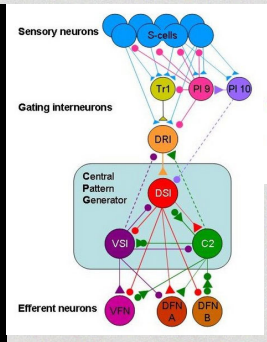
26

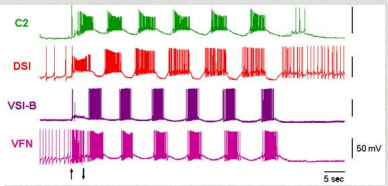
Invertebrate model systems for neuroscience

- Small numbers of neurons (as few as 1000 neurons) - this is 10,000,000 times fewer than in humans!
- Large neurons that are easy to study with electrophysiology
  - Identifiable neurons
  - Neurons can be recognized from individual animal to individual animal
- Identifiable circuits
- "Simple behaviours":
- What is the minimum neural machinery to produce a certain behaviour?
- Simple genetics
- Invertebrates with small genomes and short life cycles allow experimental genetic manipulation of the nervous system

27

Swimming in sea slugs





1. Sensory input activates DRI.
2. DRI excites DSI
3. DSI excites C2
4. C2 feeds back and excites DRI, further exciting DSI via a positive feedback loop.
5. C2 excites VSI, which inhibits DSI and C2, thereby momentarily interrupting the positive feedback loop.

Paul S. Katz (2009), Scholarpedia, 4:3638

28

Nervous system adaptability

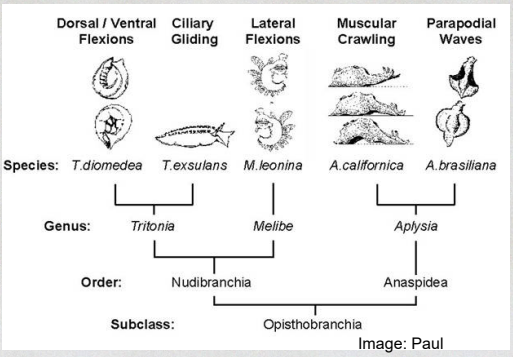


Image: Paul Katz

- Different species swim with different methods
- Serotonergic dorsal swim interneurons (DSIs) have different functions in different opisthobranchs

29